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# Contraction of Unconnected Diagrams using Least Cost Parsing

Steffen Mazanek<sup>1</sup>, Mark Minas<sup>2</sup>

<sup>1</sup> [steffen.mazanek@unibw.de](mailto:steffen.mazanek@unibw.de)

<sup>2</sup> [mark.minas@unibw.de](mailto:mark.minas@unibw.de)

Institut für Softwaretechnologie  
Universität der Bundeswehr München, Germany

**Abstract:** A free-hand diagram editor allows the user to place diagram components on the pane without any restrictions. This increase in flexibility often comes at the cost of editing performance, though. In particular it is tedious to manually establish the spatial relations between diagram components that are required by the visual language. Even worse are certain graph-like languages where it is a quite annoying task to explicitly link the node components.

In this paper *diagram contraction* is proposed for solving these issues. The editor user can just roughly arrange a set of diagram components. On request the editor automatically creates a correct diagram from these components while preserving their layout as far as possible. Moreover, for several languages diagram contraction corresponds to linking node components appropriately. Such *auto-linking* is considered useful. It even has been integrated into first commercial modeling tools.

The proposed approach can be applied to visual languages that are specified by means of hypergraph grammars. For syntax analysis an error-tolerant hypergraph parser is used, which computes a cost function by attribute evaluation. That way, unfavorable derivation (sub-)trees can be excluded at an early stage, and combinatorial explosion is mostly prevented.

**Keywords:** diagram contraction, auto-link, least cost parsing, hypergraph grammars

## 1 Introduction

This paper is motivated by the observation that many free-hand editors suffer from a poor editing performance. Since diagram components are to be placed on the pane without any restrictions or guidance, the editor user often needs to perform tedious precision work in order to establish the spatial relations required by the particular language.

Consider the language of Nassi-Shneiderman diagrams (NSDs) [NS73] as a first example. It is quite difficult to move and size the statements of an NSD such that their corners touch properly (at least without snap to grid). Experiments rather confirm the claim that users are much faster in just roughly arranging their diagram components as shown in Fig. 1a. So, couldn't the annoying precision work be done by the editor instead of the user?

As another example consider graph-like languages such as flowcharts. Here, the user needs to connect the node components manually although the intended diagram often is already clear from their *layout*. For instance, on the left-hand side of Fig. 2 an incomplete flowchart is shown. Only

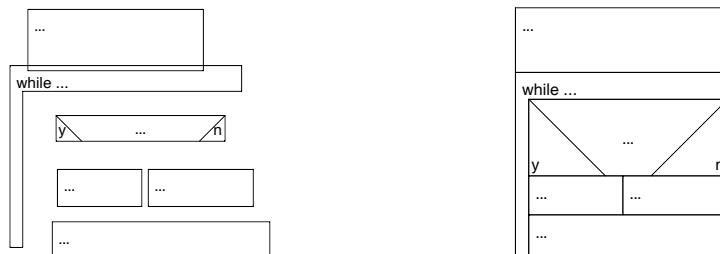


Figure 1: a) Roughly arranged NSD and b) the NSD actually intended

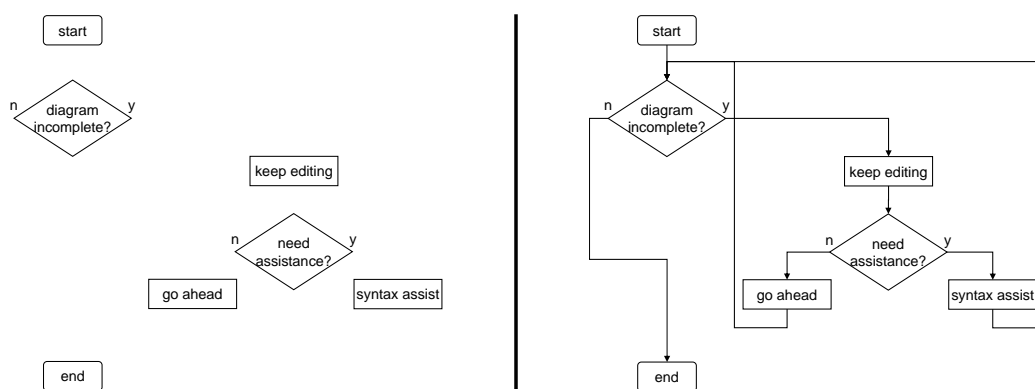


Figure 2: a) Unconnected flowchart and b) the flowchart actually intended

the node components are drawn, i.e. start and end symbols, statements, and conditions. From their arrangement it is already quite clear which flowchart the user intends to create. However, still 8 arrows (two mouse clicks each) have to be drawn in order to actually create it. If the missing arrows were derived automatically, the overall editing time would significantly decrease.

Such an “auto-link” feature has already been realized for business process models [Obj09] and incorporated into the WebSphere Business Modeler [WGK<sup>+</sup>08, GKW08]. It is described as “some magic where you simply place the activities of your business process in some approximate arrangement and your modeling tool connects them for you”. However, this solution seems to be based on a manual programming effort and cannot be reused for other languages easily. In contrast, this paper describes a generic mechanism that supports auto-link as a special case.

In the following the process of finding the correct diagram closest to a rough arrangement of diagram components is called *diagram contraction*. This paper shows that diagram contraction is both useful and feasible for a particular class of languages. The proposed approach exploits both syntactic and layout information to this end. It is based on an error-tolerant hypergraph parser that estimates repair costs for possible derivations. Therewith, unfavorable (sub-)derivations can be excluded at an early stage. At the same time, a flexible control of the parsing process is possible via the cost function. The language of NSDs is used as a running example.

**Outline:** In Sect. 2 previous work is briefly reviewed. Sect. 3 presents the method for contraction. Sect. 4 discusses the special case auto-link. Empirical results of a user study are presented in Sect. 5. Related work is discussed in Sect. 6, and Sect. 7 concludes the paper.

## 2 Previous Work

The proposed approach is based on hypergraphs as a model for diagrams [Min02], which have proven to be well-suited for that purpose. The syntax of the particular visual language then can be defined by a hyperedge replacement grammar (HRG) [DHK97]. Fig. 3 shows the HRG of NSDs. Nonterminal symbols are shaded. The first two rules (i.e., the upper row) basically state that an NSD is a non-empty chain of successive statements. A statement in turn either is a primitive statement, a condition, or a while-loop. The body of a loop and the branches below a condition have to be NSDs again, i.e. the language is recursively defined.

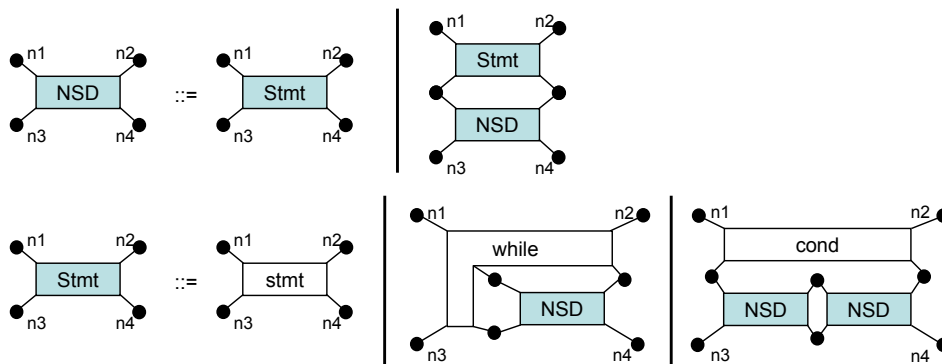


Figure 3: Hypergraph grammar of NSDs

In [MMM08a] an algorithm for *hypergraph completion* with respect to HRGs has been proposed. Given a hypergraph  $H$  and an HRG  $G$ , this algorithm embeds additional hyperedges into  $H$  in a way, such that the resulting hypergraph  $H'$  is a member of the language defined by  $G$ . This algorithm has been extended, so that it (optionally) can also glue existing nodes where required. Technically, it constructs quotient hypergraphs whose nodes actually are equivalence classes of the original nodes of  $H$ . This is shown in Fig. 4. The two isolated statements of the given hypergraph  $H$  can be combined in two different ways. An equivalence relation on the nodes of  $H$  together with a set of additional hyperedges is called a *patch* of  $H$ . The parser, hence, computes hypergraph patches that, when applied to  $H$ , yield correct hypergraphs.

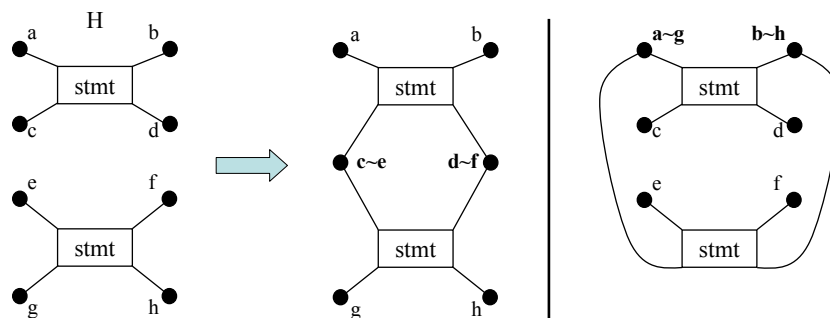


Figure 4: Application of hypergraph patches

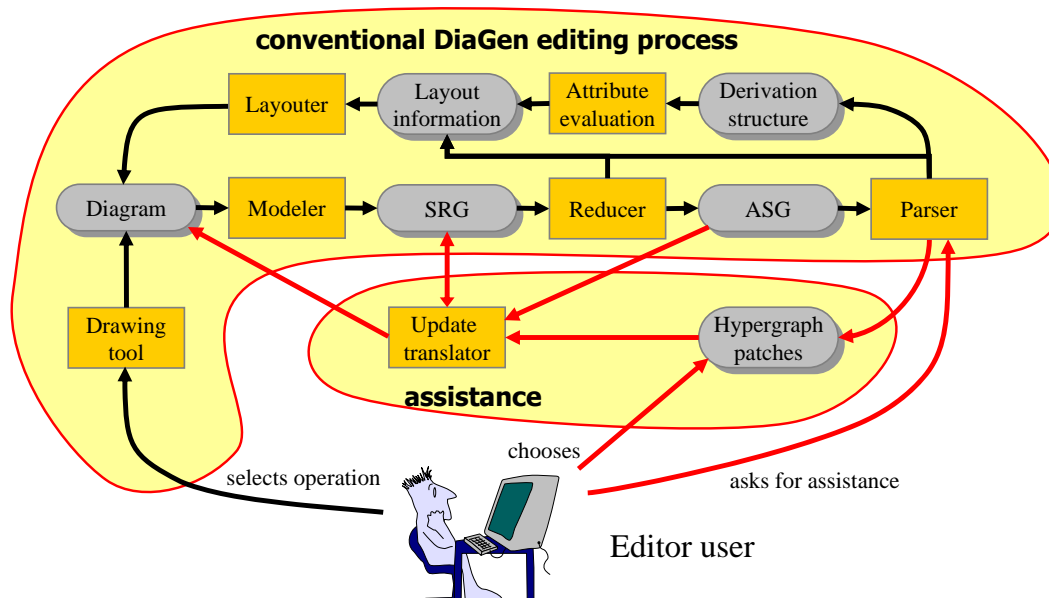


Figure 5: Extended DIAGEN editing process

Hypergraph patches can be naturally used in diagram editors [MMM08b]. That way, the DIAGEN toolkit has been extended by diagram correction and completion. The conventional DIAGEN editing process (as marked in Fig. 5) consists of several steps [Min02]: The modeler first creates a so-called Spatial Relationship (Hyper-)Graph (SRG) corresponding to the diagram. Thereafter, the reducer simplifies the SRG (similar to lexical analysis in the string setting). This results in the Abstract Syntax (Hyper-)Graph (ASG), an abstract representation of the diagram. The parser analyzes the ASG and constructs the derivation structure (if existent). Finally, the layouter uses this derivation information in order to compute a layout for the diagram.

In [MMM08b] this process has been extended as follows (cf. also Fig. 5): If a user explicitly asks for assistance, the parser is triggered again. It computes hypergraph patches of some user-defined size (determining the number of additional components). From those, the user has to choose. The selected patch is applied and embedded into the SRG using a language-specific update translator. The editor then calls the reducer and parser again, so that the layouter can arrange the new components within the actual diagram and adapt existing components if necessary.

In [MMM08c] a method has been suggested that supports diagram contraction as a special case. There, possible corrections are computed on the abstract syntax level. The quality of these corrections is evaluated *afterwards* using the layouter. Finally, that correction is applied that causes minimal changes to existing diagram components. The main challenge of this approach is the possible (likely) combinatorial explosion. For instance,  $n$  NSD statements, where no two corners touch, can be arranged in  $n!$  ways. If other kinds of components are also involved it can get even worse. The example diagram of Fig. 1a already can be corrected in 1800 [sic!] different ways. Moreover, the assessment procedure (layout) is also quite expensive. So, contraction of practical diagrams is infeasible that way.

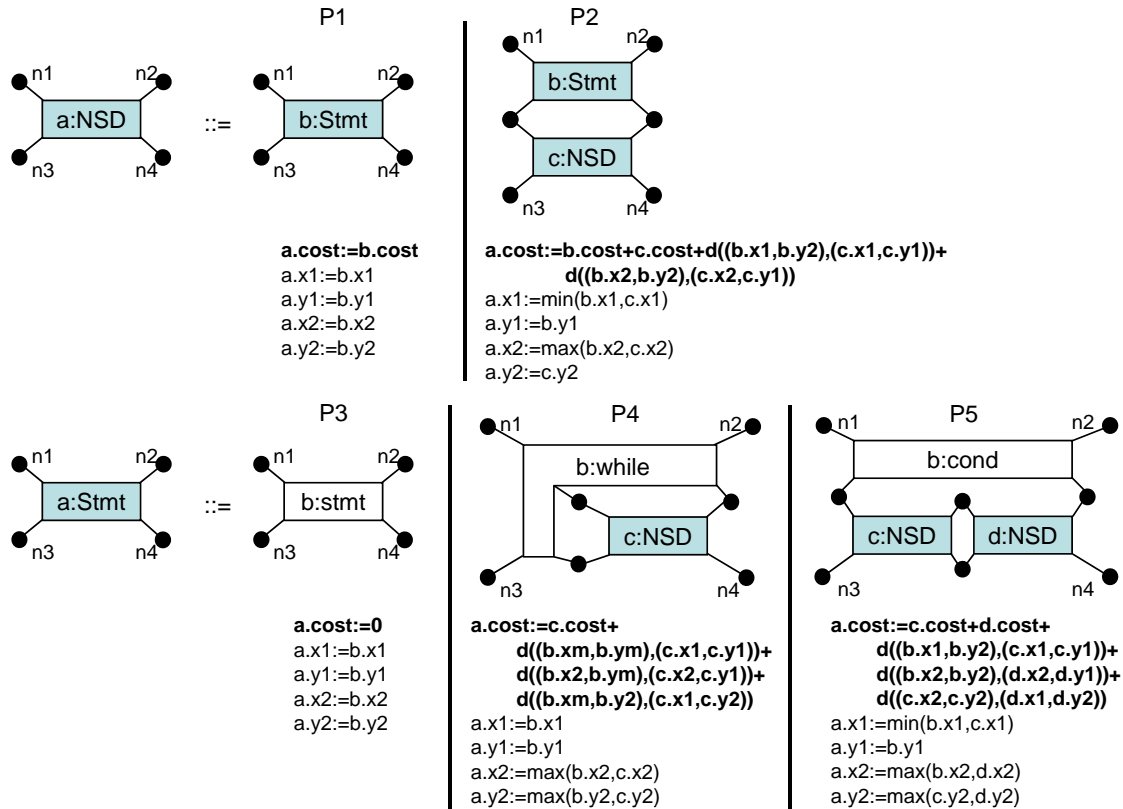


Figure 6: Cost grammar of NSDs

### 3 Realization of Diagram Contraction

This combinatorial explosion can be avoided if undesirable corrections are excluded as early as possible in the parsing process. For instance, the user is unlikely to be interested in corrections where the vertical order of his NSD statements is not preserved. So, positional information of the diagram components has to be considered while parsing the abstract representation. That way, derivations that preserve the order of statements cross out derivations that don't.

The approach proposed next exploits attribute evaluation – normally used to construct a semantic representation [Knu68] – in order to compute a *cost* for each possible derivation. This cost is an estimation of the changes that have to be performed by the layouter when this correction should be applied. For this purpose a cost attribute is assigned to each nonterminal hyper-edge. Its value gets computed bottom-up by evaluation rules that are assigned to the grammar's productions (just synthesized attributes are required).

An example of such a *cost grammar* is given in Fig. 6. In case of NSDs, nonterminal edges additionally carry attributes  $x1, y1, x2, y2$  that describe the top left resp. bottom right corner of the bounding box of the respective sub-diagram. Whenever a reduction is performed during parsing, the attributes  $x1, y1, x2, y2$  and *cost* are set as indicated by the assignments below the used production. The attributes  $xm, ym$  of the *while* edge in production P4 describe the

inner bend of a *while* component. Note that edges in the assignment part are addressed using identifiers such as  $b$  in  $b : \text{Stmt}$ .

The goal of a cost model is to punish undesirable contractions with high costs. In Fig. 6 distances between points (that ideally should coincide) are used ( $d(p_1, p_2)$  denotes the Euclidean distance between  $p_1$  and  $p_2$ ). Therefore, no costs are associated with the terminal production P3. However, there is some freedom in choosing a cost function. In general, it is not possible to define a cost function that precisely reflects the changes to existing diagram components that would have to be performed by the layouter afterwards. Indeed, this would lead to the combinatorial problem of [MMM08c] again. A reasonable estimation already yields acceptable results in practical time instead.<sup>1</sup>

Let us recall the details of error-tolerant parsing as described in [MMM08a]. First, as in the string setting, the HRG has to be transformed to Chomsky normal form. Thereby, chain productions with a single nonterminal edge on the right-hand side are eliminated. For NSDs an additional terminal production  $\text{NSD} ::= \text{stmt}$  is introduced to this end. Then possible derivation trees are constructed bottom-up by reverse application of productions, i.e. reductions. Thereby, nodes can be glued where required, i.e. an equivalence relation on nodes is computed successively. Derivations are computed layer by layer where derivations of layer  $i$  result in hypergraphs of  $i$  terminal hyperedges. The layers are constructed as follows:

- Layer 1 is created by reverse-application of terminal productions, i.e., productions with a single terminal hyperedge as right-hand side.
- Layer  $i$  ( $i > 1$ ) is created by selecting every pair of layers  $j$  ( $j < i$ ) and  $i - j$ , and combining “compatible” derivations thereof by reverse-application of nonterminal productions, i.e., productions with just two nonterminal edges as right-hand side.

### 3.1 Extension of the Parser

This parser has been extended by attribute evaluation in a straightforward way in order to support the computation of the cost attribute. Moreover, and this is the major improvement, a clean-up phase has been incorporated that follows each time after a layer has been computed.

Fig. 7 shows an example run of this extended parser. In the lower left corner an unconnected NSD is given. It consists of just three statements (whose intended order can easily be recognized by a human observer). Sizes and distances relevant for the computation of the cost function are marked. In the lower right corner the first derivation layer  $L_1$  is shown. The terminal productions  $\text{stmt} ::= \text{stmt}$  (P3) and  $\text{NSD} ::= \text{stmt}$  are applied three times each (for conciseness their “derivation nodes”<sup>2</sup> are combined indicated by the label  $\text{stmt}/\text{NSD}$ ). No costs are caused yet.

In layer  $L_2$  there are six ways of combining a  $\text{stmt}$  and an  $\text{NSD}$  at a time using the nonterminal production P2. Thereby, nodes have to be glued appropriately as indicated by  $\sim$ . The labels on top of the derivation nodes indicate which derivation nodes from layer  $L_1$  have been combined. The costs following from the cost function and the actual distances in the input diagram are also

<sup>1</sup> Here, costs are *added up* throughout the derivation. It would also be possible to define a kind of goodness, where the value 1.0 means perfect, and *multiply* goodnesses of sub-diagrams.

<sup>2</sup> The term “derivation node” refers to a node of the derivation tree in the following whereas the term “node” refers to a node of a particular hypergraph.

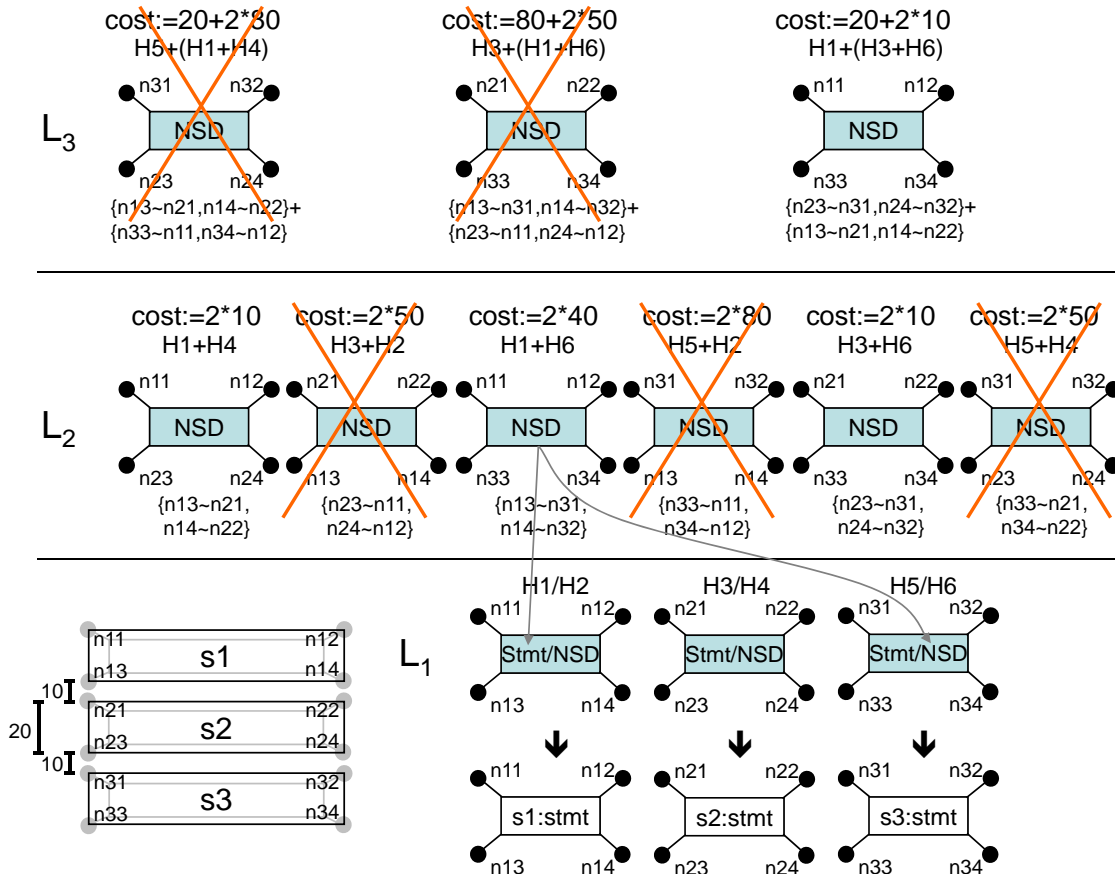


Figure 7: Example parser run

shown. After layer  $L_2$  has been computed, those derivation nodes are filtered out that cover a subset of edges of another derivation node and have the same root label, but cause higher costs.<sup>3</sup> That way,  $H3+H2$ ,  $H5+H2$  and  $H5+H4$  can be directly removed from  $L_2$ , but not  $H1+H6$ , because the cheaper derivations cover different edge sets.

In the top layer  $L_3$  then there are only three valid combinations possible. The best one is  $H1+(H3+H6)$ . This derivation is even better than just  $H1+H6$ . Consequently, for higher layers,  $H1+H6$  and all derivation nodes that have  $H1+H6$  as a sub-tree would also be removed after the computation of layer  $L_3$  is completed. In this simple example  $L_3$  is the top layer though.

So, in the clean-up phase undesirable derivation nodes are removed across lower (and equal) layers, i.e., after layer  $i$  is processed, layers 1 to  $i$  are cleaned up. The savings thanks to this improvement are significant. Tab. 1 opposes the old and the extended parser regarding the filling level of layers when parsing the NSD shown in Fig. 1a. It can clearly be seen that after processing a higher layer elements from lower layers are removed. The notation  $x/y$  is used for the currently processed layer to also provide the number  $x$  of elements in this layer before clean-up

<sup>3</sup> However, in rare cases derivation nodes could be removed that would contribute to a global optimum. In the worst case this could even result in a dead end, i.e., a solution exists but no solution is found.



layer	old parser finally	new parser after processing of layer					
		1	2	3	4	5	6
1	10	10	10	10	10	10	10
2	24		24/19	14	8	8	8
3	112			87/29	10	5	5
4	468				135/12	6	5
5	1512					42/9	4
6	2760						13/1

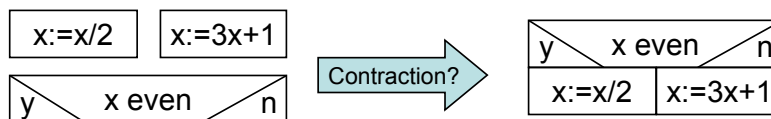
Table 1: Savings due to clean-up, number of elements in layers when parsing the NSD of Fig. 1a

(accordingly,  $y$  is the number of elements after clean-up). Removing derivation nodes in lower layers in turn further increases the performance for filling higher layers. In the example this boils down to just a single derivation in layer 6.

### 3.2 Discussion

The proposed approach significantly reduces the effort for contracting diagrams compared to [MMM08c]. However, for the contraction of large diagrams the performance is still not sufficient. The reason is that lots of undesirable derivations are kept quite long, because a better derivation at a higher layer is found too late. There are two effective ways to deal with this issue:

- Introduce a special cost  $\infty$  that directly triggers the removal of the respective derivation node. For instance, in case of NSDs it could be stated that way, that the order of primitive statements must not be changed or that a condition always has to be above its branches. As a positive effect of this approach unexpected contractions like the one shown below are directly excluded. However, it has to be accepted that the number of cases increases where contraction does not yield a solution although it exists.



- Introduce a cost bound *per component*. This cost bound is multiplied with the number of components processed by a derivation and has to be adhered to in order to actually perform a reduction. This is very effective. However, it might be a balancing act to set a reasonable cost bound that improves performance but does not lose valuable solutions.

With either of these approaches (or a combination thereof) practical performance can be achieved. Note that the presented parser still supports completion, i.e., the insertion of new edges if required. Thus, a cost can also be assigned to the introduction of each new hyperedge. In case of NSDs, depending on this cost the parser would evaluate whether it is better to insert a new statement or to relocate an existing one. However, this has not been investigated in depth yet. Some considerations about this idea had been provided in [MMM08c].

Finally, it is important to stress out that the diagram does not have to be completely unconnected. Actually, if a production can be reverse-applied without requiring any nodes to be glued, no cost is added. So the proposed approach fully respects already correct sub-diagrams. Nothing gets scrambled. Rather, fragments can be integrated into the main diagram successively.

## 4 Auto-Link

As already mentioned, the proposed approach has quite a wide scope. To understand this, one has to consider how (certain, context-free) graph-like diagrams can be modeled with hypergraphs. In this context, connecting lines and arrows often can be reduced (in DIAGEN by the reducer component, cf. Fig. 5) and, thus, are not part of the abstract syntax anymore.

As an example consider the correct flowchart shown in Fig. 2b. Its ASG is shown in Fig. 8b.<sup>4</sup> The reduction of the arrows has caused certain nodes to be glued. That way the control flow is just represented implicitly by component hyperedges visiting the same node. The same diagram without the connecting arrows had been given in Fig. 2a. Again, the corresponding ASG is shown in Fig. 8a. A least cost correcting patch for this ASG would glue the nodes such that its application just results in Fig. 8b.

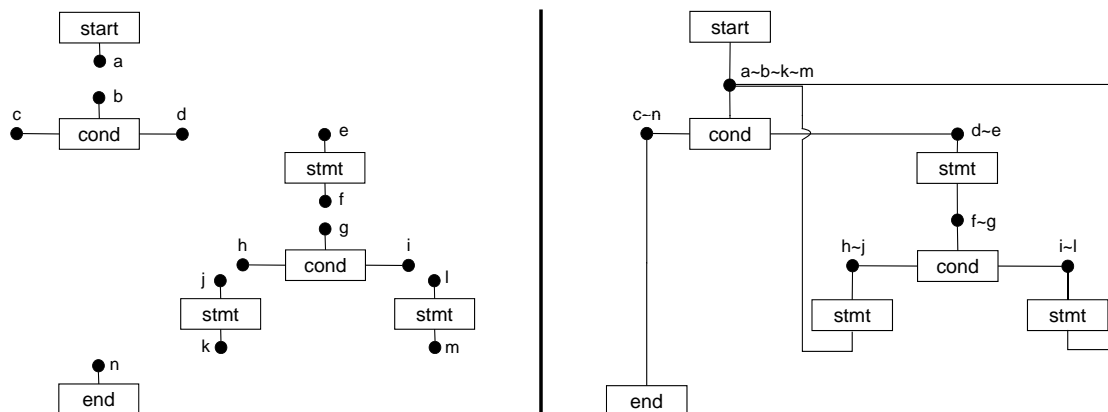


Figure 8: a) Hypergraph model of Fig. 2a and b) hypergraph model of Fig. 2b

Following the extended editing process as shown in Fig. 5, the update translator then introduces new arrows between the respective components where nodes have to be glued. So, diagram contraction here absolutely coincides with the described auto-link feature. To improve the readability of the resulting diagram an edge router can be added to the layouter, so that appropriate bend points for the connectors are inserted automatically.

A cost grammar for flowcharts also can be created in a quite straightforward way. In the developed flowchart editor, costs estimate the length of the arrows to be introduced by the update translator. In the context of flowcharts there is one further issue though, which does not occur so often in the context of NSDs: It can easily happen that several derivations are cheapest at

<sup>4</sup> For further information regarding this example consult [Min02], where flowcharts are used as a running example to clarify the DIAGEN approach.

the same time. The editor chooses from those in a non-deterministic way. The user might be surprised though. For instance, the editor might not create a loop in Fig. 2a but rather just a simple branching. General preferences of course can be reflected by the cost function.

Auto-link significantly improves the editing performance. Whereas in case of NSDs just the precision work is saved, this time several new diagram components, i.e. the missing arrows, are inserted automatically. Usually two (quite precise) mouse clicks are necessary for drawing a single arrow manually (bend points not even included). It is worthwhile to save those – at least where possible.

Unfortunately, the proposed approach cannot be applied to non-context-free languages like class diagrams: First of all, such languages do not exhibit a recursive structure as required. Furthermore, edges like associations are first-class citizens of the abstract syntax. And finally, it is hard to derive meaningful connections just from the *layout* of a set of classes.

However, several useful DIAGEN editors with auto-link have been realized already: logic gates, trees, structured flowcharts and structured business process models (even supporting embedded messages). The latter particularly shows that the proposed approach is also applicable to (at least some) real-world languages.

## 5 User Study

In this section the results of a first (limited) user study are provided. It has been conducted in order to verify the assumption that it is much faster to draw a roughly arranged diagram than a concise one. Test users had to proceed as follows:

- learning stage: getting used to the NSD resp. flowchart editor
- creation of a given concise NSD resp. complete flowchart consisting of 11 resp. 13 components (without counting arrows)
- creation of a roughly arranged version of the same NSD resp. an unconnected version of the same flowchart, and contraction thereof; Fig. 1a actually shows an extract of the solution of one of the users

The empirical results shown in Tab. 2 indeed support the claim of this paper. The task performance is increased by a factor of more than 1.5 (at least in these scenarios). All drawn NSDs had been contracted by the editor as intended. In case of flowcharts, in total three arrows had been not drawn as intended (but still in a reasonable way). Remarkably, it can be observed that users even get better in drawing roughly arranged diagrams. For instance, in a second run several users had not created the diagram from top to bottom anymore, but rather by kind of component (i.e., many statements had been added at once). That way, the time for switching the component kind had been saved.

## 6 Related Work

In contrast to free-hand editors, structure editors are known for their good editing performance. Therefore, diagram contraction is not as important in that context. A structure editor prevents the

User	time for concise NSD	time for rough NSD	improvement factor
1	55s	33s	1.67
2	80s	45s	1.78
3	63s	33s	1.91
4	58s	32s	1.81
average	64s	36s	<b>1.8</b>

User	time for complete fc	time for just nodes	improvement factor
1	55s	20s	2.75
2	70s	30s	2.33
3	68s	30s	2.67
4	63s	28s	2.25
average	64s	27s	<b>2.4</b>

Table 2: Empirical results for NSDs and flowcharts

user from drawing an incorrect diagram, i.e. an unconnected flowchart could not even be created. With a structure editor diagrams can only be manipulated by a predefined set of operations that transform correct diagrams into (other) correct diagrams. An example for such an operation in a flowchart editor would be to insert a new statement (with corresponding arrows) after a selected one. However, users still like to draw their diagrams freely just following the flow of their uninhibited associations. The operations of a structure editor impose significant restrictions to the users and, thus, hinder the editing process. In the context of sketch tools structure editors cannot be used at all, because it is inconvenient to perform the required selections with a pen.

Actually, a different kind of cost grammars has already been used successfully in the context of sketch tools. They appear to be well-suited for reasoning about the quality and interpretation of sketches, cf. [BM08]. In this approach, the resolution of ambiguities, which frequently occur in hand-drawn diagrams, is effectively supported by syntax analysis. That way, a more reliable recognition has been achieved. Since the authors achieved practical performance straight away, no clean-up phase as described in this paper had to be introduced.

Slight correction of geometric errors is also provided in CIDER [CM03] and (conventional) DIAGEN [Min02]. Both systems exploit layout constraints to this end. However, there is only a kind of tolerance threshold, which cannot be increased too much. Otherwise surprising results would be the consequence. Auto-link is also not supported there.

Finally, it has to be admitted that the practical importance of some kind of diagram contraction, namely auto-link, has been recognized already in [WGK<sup>+</sup>08, GKW08].<sup>5</sup> However, the corresponding plugin is closed source and not officially released yet. The authors also do not describe their realization. Since the WebSphere Business Modeler is a special-purpose tool (and not a *meta*-tool) their solution (probably) cannot be used beyond business process models easily.

<sup>5</sup> There, only activities need to be arranged. From their layout the missing gateways and sequence arrows are derived.

## 7 Conclusion

The proposed approach to diagram contraction is promising for several reasons: First of all, it can be used to improve the editing performance and accessibility of free-hand diagram editors. It also has a positive impact on an editor's "joy of use". Furthermore, the attribution of the grammar with a cost function has appeared to be very handy. By this means the editor developer has a much finer control of the parsing process.

An editor with support for diagram contraction allows even freer editing. The distraction caused by the tedious precision work can be significantly reduced. First measurements have been conducted and the results confirm our original guess: The editing performance for drawing a given diagram is improved by a factor of more than 1.5. The recognition rate is acceptable (there is the typical trade-off with performance). No additional specification effort is required except for the cost function. As an important special case of diagram contraction the auto-link feature has been discussed. Therewith, the diagram components of certain graph-like languages can be connected automatically, which increases the editing performance even more.

In the future we would like to improve the support for the non-context-free parts of languages. At the moment those are not actively supported but rather just ignored (like messages in a structured business process model). Furthermore, we would like to reduce the additional specification effort of providing a cost grammar. It might be possible to derive a reasonable cost grammar from a constraint hypergraph grammar [MV93], which often is defined already for the sake of layout.

Screencasts of the NSD and flowchart example editors (including demonstrations of diagram contraction and auto-link) can be found at <http://www.unibw.de/inf2/DiaGen/assistance/>. The editors can be downloaded from there, too.

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